XVI. *Remarks on the employment of Oblique Riders, and on other alterations in the construction of Ships. Being the substance of a Report presented to the Board of Admiralty, with additional demonstrations and illustrations. By* Thomas Young, *M. D. For. Sec. R. S.*

Read March 24, 1814.

1. *Introductory Observations.*

THE advantage derived from the employment of forces acting obliquely with respect to each other, in a variety of cases which occur in practical mechanics, has been demonstratively established by theoretical writers on the subject; and attempts have often been made to extend the application of the principle very considerably in the art of ship-building; but hitherto with very little permanent success. Mr. SEPPINGS's arrangements are in many respects either new or newly modified; and the results of their actual employment, in the repair of the Tremendous, appear to be sufficiently encouraging to entitle them to a careful and impartial investigation, both with regard to the theory on which they are supposed to be founded, and to the facts which may be produced in their favour. The question, respecting the best disposition of the timbers of a ship, is by no means so easily discussed, as may be supposed by those, who have considered the subject but superficially; and if we allowed ourselves to be influenced by a few hasty arguments or experiments, we might be liable to the most dangerous errors: on the other hand, it may easily happen

that objections to the application of those arguments or experiments, which may occur at first sight, may be capable of being removed by a more minute investigation: and the importance of the subject requires, that no assistance, which can be afforded by the abstract sciences, should be withheld from the service of the public, even by those who have no professional motives for devoting themselves to it.

2. *Forces acting on a Ship.*

The first consideration that is necessary, for enabling us to judge of the propriety of any arrangement respecting the construction of a ship, is to determine the nature and magnitude of the forces which are to be resisted; and the second, to inquire in what manner the materials can be arranged, so as best to sustain the strains which these forces occasion. The principal forces, which act on a ship, are the weight of the whole fabric with its contents, the pressure of the water, the impulse of the wind, and the resistance of the ground or of a rock: and we must endeavour to ascertain the degree in which any of them have a tendency to bend the ship longitudinally or transversely, or to break through any part of her texture; and to inquire into those causes, which are likely to promote or to obviate the decay of the substances employed.

3. *Causes of arching. Weight.*

It is unnecessary to explain here the well known inequality of the distribution of the weight and pressure, which causes almost all ships to have a tendency to arch or hog, that is, to become convex upwards, in the direction of their length. It is possible that there may be cases in which a strain of a very

different nature is produced: but in ships of war, this tendency appears to be universal. It is however very different in degree in the different parts of a ship; and of course, still more different according to the different modes of distribution of the ballast and stores, which may occur in different ships: but in ordinary cases, it will probably be found nearly such as is represented in the calculations subjoined in the note,* de-

* In a modern 74 gun ship, fitted for sea, the length being 176 feet, the breadth $47\frac{1}{2}$, the forces are thus distributed.

Aftermost	49 f.	Weight 699	Pressure 627	Difference 72 tons.
Next	20	297	405	−108
	50	1216	1098	118
	20	290	409	−119
	37	498	461	37
	176	3000	3000	00

Now the laws of equilibrium will not allow us to suppose these forces concentrated in the middle of the respective portions, or equally distributed through them; and it becomes necessary, that one of the weights should be situated further forwards; which must be that of the foremost portion, containing the bowsprit and its rigging. It is also natural to suppose the excesses of weight and pressure distributed with as few abrupt changes as possible, so as to neutralise each other at the common termination of the adjoining portions, and to become more unequal in parts more remote from these neutral points. Thus the excess of weight in the first 49 feet being 72 tons, it may be supposed to begin at the rate of $\frac{144}{49}$ tons per foot, and to diminish gradually and equably, so that its centre of action will be at the distance $\frac{49}{3}$ from the end: the excess of pressure must increase in the next place, until at the distance of 59 feet from the stern, it becomes $\frac{108}{10}$ per foot, and must then diminish until it vanishes at 69, where the excess of weight must begin to prevail, becoming, at 94, $\frac{118}{25}$ per foot, and vanishing at 119. The excess of pressure might then be supposed to increase gradually through the next portion, in order to avoid an abrupt change at its extremity; but this supposition would still be insufficient, and it becomes necessary to imagine that for 6.6 feet the forces remain neutralised, and the pressure then prevails, so that its excess becomes at last $\frac{119}{6.7} = 17.7$ per foot: it must then decrease for 17.5

duced from data which have been obligingly furnished by an acute and experienced member of the Navy Board.

feet, and the excess of weight at the extremity must become 19.7 per foot, the neutral point being at 156.5. The equilibrium of the forces will then be expressed by the equation $72 \times 16.3 - 108 \times 59 + 118 \times 94 - 119 \times 134.5 - 155 \times 144.8 + 192 \times 169.5 = 0$, which is sufficiently accurate for every purpose.

From this distribution of the forces, we obtain a determination of the strain for each point of the respective portions, which is in the joint ratio of the magnitudes and distances of all the forces concerned, on either side of the point, reduced into a common result. For the first portion it is $\frac{144}{49}x \times \frac{1}{2}x - \frac{1}{2}.\frac{144}{49}.\frac{x}{49}.x\frac{1}{3}x = \frac{72}{49}x^2 - \frac{1}{6}.\frac{144}{49}.\frac{x^3}{49}$, x being the distance from the stern: for the 2d, $72\,(x - 16\frac{1}{3}) - \frac{1}{6}.\frac{108}{10}.\frac{(x-49)^3}{10}$: 3d, $72\,(x - 16\frac{1}{3}) - 54\,(x - 55\frac{2}{3}) - \frac{108}{20}\,(x - 59)^2 + \frac{1}{6}.\frac{108}{100}.(x - 59)^3$: 4th, $72\,(x - 16\frac{1}{3}) - 108\,(x - 59) + \frac{1}{6}.\frac{118}{25}.\frac{(x - 69)^3}{25}$: 5th, $72\,(x - 16\frac{1}{3}) - 108\,(x - 59) + 59\,(x - 94) + \frac{118}{50}\,(x - 94)^2 - \frac{1}{6}.\frac{118}{25}\frac{(x - 94)^3}{25}$: 6th, from 119 to 125.6, $72\,(x - 16\frac{1}{3}) - 108\,(x - 59) + 118\,(x - 94)$: for the 7th, we must add to this expression $-\frac{1}{6}.\frac{119}{13.4}.\frac{(x - 125.6)^3}{13.4}$: and, in the last 37 feet, the strain will be expressed by $(176 - x)\,19.7 \times \frac{1}{2}(176 - x) - \frac{1}{6}\,19.7\,\frac{(176 - x)^3}{19.5}$. Hence we find the strain, at seven points, 22 feet distant from each other and from the ends, 605, 1993, 2815, 2244, 2655, 4610, and 1875; and by taking the fluxion of x in the seventh portion, we determine the maximum at $141\frac{2}{3}$ feet, amounting to 5261 tons, supposed to act at the distance of one foot.

In order to form an idea of the curve which would be produced by such a strain, acting on a uniformly flexible substance, we may consider the curvature as represented by the second fluxion of the ordinate y, and by finding and correcting the fluent separately for each portion, we may obtain the ordinate or fall at any given point corresponding to a given extent of arching of the whole fabric. It will however be sufficiently accurate for this purpose, to consider the forces as concentrated in a limited number of points, dividing those which act in the extreme portions into two parts, in order that the curvature may be continued to the ends; so that the whole of the forces may be thus distributed: at 0, 36; at $32\frac{2}{3}$, 36; at 59, $-$108, at 94, 118; at 134.5,

Longitudinal Pressure.

To this strain another is added, from a cause, which, although not very inconsiderable, appears hitherto to have

— 119; at 144.8, — 155; at 163, 96; and at 176, 96. The strain for each portion may then be represented by $a - bx$, whence $\ddot{y} = a\dot{x}\dot{x} - bx\dot{x}\dot{x}$, $\dot{y} = ax\dot{x} - \frac{1}{2}bx^2\dot{x} + c\dot{x}$, and $y = \frac{1}{2}ax^2 - \frac{1}{6}bx^3 + cx + d$. It will be most convenient, in calculation, to make x begin anew with each portion, setting out from the middle, and to divide the numbers by 100, in order to shorten the operations: thus, for the middle portion, from 88 to 59, the strain will be $.2028 + .36x$, a being .2028, and $b = -.36$; and when x becomes .22, y is .00552, and when $x = .29$, $\frac{\dot{y}}{\dot{x}} = .0740$, and $y = .0011$; which values being substituted in the equations for the next portion, we have $c = .074$, and $d = .0011$: and by going through the whole length in this manner, we find the fall at the extremes and at seven equidistant intermediate points, .08697, .05325, .02514, .00552, 0, .00507, .02531, .06705, and .12325. If we wish to find the point at which the curve is parallel to the chord of the whole, we must inquire where $c = (.12325 - .08697) : 1.76$, which will be at 98 feet, or 10 feet before the midships.

We must next determine the magnitude of the strain arising from the longitudinal pressure acting on the lower part of the ship only. The resistance being supposed to be proportional in the first instance to the degree of compression or extension, according to the common and almost necessary law of the constitution of elastic bodies, and varying also in the direct ratio of the strength of the fabric, which may be assumed to be either equable, or, in the case of a ship, proportional to the distance from a point more or less remote, we must form an equation of equilibrium for the absolute equality of the forces in opposite directions, and another for their powers of acting with respect to any given point as the fulcrum of a lever. Thus the fluxion of the absolute resistance at the distance x from the upper surface, supposing the strength to be as $a + x$, and the neutral point, at which the compression and extension cease, to be at the distance b, will be $(b-x)\,c\,(a+x)\,\dot{x} = c\,(ab-ax+bx-xx)\,\dot{x}$, which, when x is equal to the depth d, must become equal to the force f producing the strain, or $f = c\,(abx - \frac{1}{2}ax^2 + \frac{1}{2}bx^2 - \frac{1}{3}x^3)$: and for the second equation, referring the forces to the upper surface as a fulcrum, the fluent of $c\,(b-x)\,(a+x)\,x\dot{x}$, must be equal to ef, e being the distance at which the force e is applied; whence $ef = c\,(\frac{1}{2}abd^2 - \frac{1}{3}ad^3 + \frac{1}{3}bd^3 - \frac{1}{4}d^4)$. Now if we make $a = d = x$, the equations become

escaped notice; that is, the partial pressure of the water in a longitudinal direction, affecting the lower parts of the ship only, and tending to compress and shorten the keel, while it has no immediate action on the upper decks. The pressure, thus applied, must obviously occasion a curvature, if the angles made with the decks by the timbers are supposed to remain

$c(\frac{3}{2}bd^2-\frac{5}{6}d^3)=f$, and $c(\frac{5}{6}bd^3-\frac{7}{12}d^4)=ef$, and from the former we have $c(\frac{5}{6}bd^3-\frac{25}{54}d^4)=\frac{5}{9}df$; and, by subtraction, $\frac{13}{108}cd^4=(\frac{5}{9}d-e)f$: consequently the force f may be considered as acting on a lever of the length $e-\frac{5}{9}d$: and if we take any other value for a, the fractional multiplier of d, instead of $\frac{5}{9}$, will be $\frac{3a+2d}{6a+3d}$, thus if $a=\frac{1}{2}$, we have $e-\frac{7}{12}d$ for the length of the lever. In order to find the mean distance e at which the pressure of the water acts, we may suppose the form of the mean transverse section of the ship to be parabolic, and the area such as to correspond to the bulk of 3000 tons of water, each containing 35 cubic feet, the length being 176 feet, and the breadth $47\frac{1}{2}$, whence the depth must be 18.84 feet: then the centre of gravity of a parabola being at the distance of $\frac{3}{5}$ of the depth from the vertex, (VINCE's Fluxions, p. 101,) and the centre of oscillation at $\frac{5}{7}$, when the point of suspension is at the vertex (p. 111,) the distance of these points $\frac{4}{35}$ will be increased to $\frac{6}{35}$, when the point of suspension is removed to the termination of the absciss, and the distance of the centre of pressure from the vertex will be $\frac{3}{5}-\frac{6}{35}=\frac{3}{7}$, and $\frac{3}{7}\times 18.84=8.074$, which, subtracted from $\frac{4}{9}\times 40=17.777$, leaves 9.703 for the length of the lever. Now the magnitude of the pressure on this section must be to 3000 tons, as the depth of the centre of gravity, 7,536 feet, to 176, that is, 128.45 tons, which, acting at the distance 9.703, will produce a strain of 1247 tons, or, in the terms of the preceding calculation, .1247, which is the multiple of $\frac{1}{2}x^2$ indicating the fall. These different causes of arching being independent of each other in their operation, their effects will be simply united into a common result: and the whole curvature of the ship, supposing its strength equable throughout its length, may be thus represented.

Dist. from the stern	0	22	44	66	88	110	132	154	176
Strain	1247+0	605	1993	2815	2224	2655	4610	1875	0
Fall -	.04828	.02716	.01207	.00302	.00000	.00302	.01207	.02716	.04828
	.08697	.05325	.02514	.00552	.00000	.00507	.02531	.06705	.12325
	.13525	.08041	.03721	.00854	.00000	.00809	.03738	.09421	.17153
For 12 inches of arching	10.58	6.29	2.91	.67	.00	.63	2.93	7.37	13.42

unaltered, while the keel is shortened, in the same manner as any soft and thick substance, pressed at one edge between the fingers, will become concave at the part compressed, (Lect. Nat. Phil. I. Pl. 9. F. 117); and this strain, upon the most probable supposition respecting the comparative strength of the upper and lower parts of the ship, must amount to more than one third as much as the mean value of the former, being equivalent to the effect of a weight of about 1000 tons, acting on a lever of one foot in length, while the strain, arising from the unequal distribution of the weight and the displacement, amounts, where it is greatest, that is, about 37 feet from the head, to 5260, in a 74 gun ship of the usual dimensions; and although the strain is considerably less than this exactly in the middle, and throughout the aftermost half of the length, it is no where converted into a tendency to "sag," or to become concave. It must however be remembered, that when arching actually takes place from the operation of these forces, it depends upon the comparative strength of the different parts of the ship and their fastenings, whether the curvature shall vary more or less from the form, which results from the supposition of a uniform resistance throughout the length. An apparent deviation may also arise from the unequal distribution of the weight through the breadth of the ship: thus the keel may actually sag, under the step of the mainmast, even when the strain, as here calculated, indicates a contrary tendency with respect to the curvature of the whole ship.

Force of the Waves.

The magnitude of the strain on the different parts of a ship is subjected to very material alterations, when she is exposed

to the forces of the wind and waves. The effect of the wind is generally compensated by a change of the situation of the actual water line, or line of fluitation, so that its amount may be estimated from the temporary or permanent inclination of the ship; and the force of the waves may be more directly calculated from their height and breadth. These two forces can seldom be so applied, as to combine their effects, in producing a strain of the same kind in their full extent; it will therefore be sufficient for our purpose to determine the probable amount of the force of the waves, which is more materially concerned in affecting the longitudinal curvature than that of the wind. As a fair specimen of the greatest strain that is likely to arise from this cause in any common circumstances, we may consider the case of a series of waves 20 feet in height, and 70 in breadth; the form being such, that the curvature of the surface may be nearly proportional to the elevation or depression: a single wave might indeed act more powerfully than a continued series, but such a wave can scarcely ever occur singly. We shall then find upon calculation,* that the greatest

* The strain, produced by the pressure of waves of given magnitude, may be calculated from the comparison of the displacement with respect to their surface, compared with the displacement with respect to a level surface. It is true that the pressure upon the ship's bottom is not immediately derived from the temporary height of the nearest portion of water; but the horizontal motion of the water, which is the proximate cause of the elevation, is equally capable of affecting the fluid under a floating body, and of causing a pressure against it: the effect being nearly similar to the transmission of sound through an elastic medium. In other cases, the actual height of the fluid, over every particle concerned in the transmission of a wave, has been supposed, in calculations, to determine the pressure on it: but, whether from the necessary constitution of a fluid, or from the imperfect fluidity of fluids actually existing, it appears that there is a lateral communication of pressure within a certain angular extent, somewhat like the lateral friction attending the motions of fluids; and

strain takes place, in a 74 gun ship, at the distance of about 18 feet from the midships, amounting to about 10,000 tons, at the

this is the most probable cause of the deficiency in the velocity of waves, when their breadth is very small in proportion to the depth of the fluid. In the present calculation, however, the considerations are more simple, and we have only to determine the effect of the difference produced during the passage of a wave in the quantity of water displaced by the ship, with respect to the general surface. The total height of the waves being 20 feet, and the total breadth 70, the section being supposed to constitute a figure of sines, the elevation or depression, at the distance x from the middle, will be 10 cos. px, p being $\frac{6.2832}{70} = .08976$, the fluxion of the area $10\dot{x}$ cos. px, and the fluent $\frac{10}{p}$ sin. px; at the constant distance z from the middle, the fluxion of the p strain will be $(x - z)\ 10\dot{x}\varsigma px$, in order to find the fluent of which we must take the fluxions of $x\mathfrak{f}px$, and ςpx, which are $\dot{x}\mathfrak{f}px + xp\dot{x}\varsigma px$, and $- p\dot{x}\mathfrak{f}px$; hence $\int x\dot{x}\varsigma px = \frac{1}{p}\ x\mathfrak{f}px + \frac{1}{pp}\ \varsigma px$; and the fluent of the strain will be $\frac{10}{p}\ (x - z)\ \mathfrak{f}px + \frac{10}{pp}\ \varsigma px + c$, which must vanish when $x = z$, so that $c = -\frac{10}{pp}\ \varsigma pz$: now, when $x = a$, the corrected fluent becomes $\frac{10}{p}\ (a - z)\ \mathfrak{f}pa + \frac{10}{pp}\ \varsigma pa - \frac{10}{pp}\ \varsigma pz$; and if we take the fluxion of this, making z variable, we find, for the maximum, $-\frac{10}{p}\dot{z}\mathfrak{f}pa + \frac{10}{p}\ \dot{z}\mathfrak{f}pz = 0$, and $\mathfrak{f}pz = \mathfrak{f}pa$, so that z must be $a - 70 = 18$, whence the greatest strain is found, $\frac{10}{p} \times 70 \times .999 = 7791$, expressed in square feet of the longitudinal section, which, for a ship $47\frac{1}{2}$ feet wide, may be reduced into tons, by multiplying it by $\frac{47.5}{35}$, and will become 10572. It is true, that if the waves allowed time for the ascent or descent of the ship, so that she might float in equilibrium, the greatest strain would be little more than $\frac{2}{3}$ of this weight; but the elevating force in the case here calculated being only $\frac{1}{10}$ of the whole weight, it would require almost a second to raise the ship 1.265 feet, and to restore the equilibrium; so that notwithstanding its gradual application, dependent on the progressive velocity of the waves, which varies with the depth of the fluid, there must be an interval during which it operates very nearly in its whole extent, especially as the occurrence of a partial obstruction tends to increase the total height of a wave at the point where it is situated.

instant when the ship is in a horizontal position, while, in more common cases, when the waves are narrower, the strain will be proportionally smaller and nearer to the extremity. Hence it appears that the strain produced by the action of the waves may very considerably exceed in magnitude the more permanent forces derived from the ordinary distribution of the weight and pressure, being, according to this statement, nearly three times as great; so that when both strains cooperate, their sum may be equivalent to about 15,000 tons, acting on a lever of one foot, and their difference, in opposite circumstances, to about 5000. There may possibly be cases in which the pressure of the waves produces a still greater effect than this; it may also be observed, that the agitation accompanying it tends to make the fastenings give way much more readily, than they would do if an equal force were applied less abruptly. At the same time, it is not probable that this strain ever becomes so great, as to make the former perfectly inconsiderable in comparison with it, especially if we take into account the uninterrupted continuance of its action: it appears therefore to be highly proper that the provision made for counteracting the causes of arching should be greater than for obviating the strain in the contrary direction: for example, that if the pieces of timber, intended for opposing them were, on account of the nature of their fastenings, or for any other reason, more capable of resisting compression than extension, they should be so placed as to act as shores rather than as ties: although it by no means follows, from the form which the ship assumes after once breaking, that the injury has been occasioned in the first instance by the immediate causes of arching: since, when the fastenings have been loosened by a force of

any kind, the ship will naturally give way to the more permanent pressure, which continues to act on her in the state of weakness thus superinduced.

4. *Breaking transversely.*

The pressure of the water against the sides of a ship has also a tendency to produce a curvature in a transverse direction, which is greatly increased by the distribution of the weight, the parts near the sides being the heaviest, while the greatest vertical pressure of the water is in the neighbourhood of the keel. This pressure is often transmitted by the stanchions to the beams, so that they are forced upwards in the middle: when they are unsupported, the beams are more generally depressed in the middle, by the weight of the load which they sustain; while the inequality of the pressure of the water cooperates with other causes in promoting the separation of the sides of the ship from the beams of the upper decks. On the other hand, the weight of the mainmast often prevails partially over that of the sides; so that the keel is forced rather downwards than upwards in the immediate neighbourhood of the midships. The tendency to a transverse curvature is observable, when a ship rests on her side, in the opening of the joints of the planks aloft, and in their becoming tighter below; although this effect depends less immediately on the absolute extension and compression of the neighbouring parts, than on the alteration of the curvature of the timbers in consequence of the pressure.

5. *Lateral Curvature.*

In such a case there is also an obvious strain tending to produce a lateral curvature; and shores are sometimes employed to prevent its effects, when a ship is " hove down" on her side. This indeed is comparatively a rare occurrence; but when a series of large waves strikes a ship obliquely, they must often act in a similar manner with immense force: the elevation on one side may be precisely opposite to the depression on the other; and the strain from this cause can scarcely be less than the vertical strain already calculated: but its effects are less commonly observed, because we have not the same means of ascertaining the weakness which results from it, by the operation of a permanent cause. When a ship possesses a certain degree of flexibility, she may in some measure elude the violence of this force by giving way a little for the short interval occupied by the passage of the wave; but it may be suspected that her sailing, in a rough sea, must be impaired by such a temporary change of form.

6. *Grounding.*

When a ship takes the ground, she may either give way at once to the stroke of a rock, or rest on a bottom more or less soft, until she is either wholly or partially abandoned by the water. In the former case, her resistance must depend in great measure on the parts in the immediate neighbourhood of the injury: in the latter, it may happen, that she may be supported by so large a surface, as to be more in danger of parting aloft than of being crippled below. Commonly, however, the floor timbers are forced in at one end, the first fut-

tocks, which are their immediate continuations, being broken off; and sometimes the opposite ends of the floor timbers are forced out, especially in large ships without riders, their attachment to the keel remaining unimpaired.

7. *Decay.*

The causes which promote the decay of timber are only so far understood, as we are acquainted by experience with their effects. A partial exposure to moisture appears to be by far the most general of these causes: it is well known that total submersion does not accelerate decay; a surface which is kept moist by imperfect contact with another, so that a portion of water is retained between them by capillary attraction, seems always to be the part at which the timbers begin to rot; while both the surfaces completely exposed either to the drier air, or to the water, and those which are wedged closely together, and press strongly against each other, remain perfectly sound.

8. *Means of resistance.*

We are next to inquire into the comparative advantages of different angular positions of the timbers of a ship for resisting the forces which have been described; and in particular how far the arrangements, which have been proposed by Mr. Seppings, are better calculated for the purpose, than the common modes of construction. Whatever opinion we may ultimately form of these arrangements, they are by no means sufficiently justified by the experiments which have been exhibited in illustration of them. These experiments show, that when two parallel planks, (Plate XI., fig. 1,) have loose pieces interposed, extending perpendicularly from one to the other,

they are incomparably weaker, with respect to any transverse force, than when the intermediate pieces are in an oblique direction, so as to constitute a frame, which can only be bent as a whole. But it cannot for a moment be imagined, that the planks of a ship are connected with the timbers in as loose a manner as these transverse braces, which will scarcely support their own weight for the purpose of the experiment; and in fact the comparison would have required, that the whole space included by the parallelogram should be filled up in each case by similar braces, or at least that the two planks should have been firmly united at the loose end to the transverse braces (fig. 3); and it is demonstrable that in this case the same weight would have broken the pins, as if one of the planks had been oblique, or as if the planks had remained parallel, and had been connected by oblique pieces.

Such a result would, however, be far from proving the inutility of the addition of oblique braces to a rectangular frame: for the kind of strength, required for any particular purpose, is not always determined by the magnitude of the force which would be capable of breaking the substances concerned, although the power of resisting such a force is properly called strength, in the most limited sense of the term: but there are many occasions on which stiffness or inflexibility is of still greater consequence than strength, and others again on which flexibility is of material advantage. A coach spring, consisting of ten equal plates, would be rendered ten times as strong, if it were united into one mass, and at the same time a hundred times as stiff, bending only one hundredth of an inch with the same weight that would bend it a whole inch in its usual state, although nothing would be gained by the union

with respect to the power of resisting a very rapid motion, which I have, on another occasion, ventured to call resilience. (Lect. Nat. Phil. I. p. 143. II. p. 50.) Now it appears to be extremely difficult to unite a number of parallel planks so firmly together, by pieces crossing them at right angles, as completely to prevent their sliding in any degree over each other: and a diagonal brace of sufficient strength, even if it did not enable the planks to bear a greater strain without giving way, might still be of advantage, in many cases, by diminishing the degree in which the whole structure would bend before it broke.

The strength of a simple rectangular frame, firmly fixed at one end, is rendered somewhat less than double by perfectly fastening the joints at the other (fig. 4,) and the stiffness is nearly quadrupled.*

* When two horizontal bars are firmly fixed at one end only, and simply united at the other end by a vertical piece, their immediate joint force in resisting flexure remains unaltered; but if the vertical piece is firmly fixed to the ends of the bars, it may be considered as a lever held in equilibrium by four forces, arising from the repulsive and cohesive powers of the separate bars; and the sum of these forces must vanish when reduced to the same direction, while the sum of their actions, referred to any point as a fulcrum, vanishes also: and it is obvious that the total compression of the one bar will initially be equal to the total extension of the other, provided that their strength be equal. Hence, if the mean distance of the bars be a, and the depth b, reckoned between the centres of action of the respective forces, which in perfectly elastic bodies will be $\frac{2}{3}$ of the whole depth, the first force being x, and the second $-y$, the third will be y, and the fourth $-x$, and, from the equilibrium with respect to the point of application of the first force as a fulcrum, we have the equation $-by+ay-(a+b)\,x=0$, and $x=\frac{a-b}{a+b}y$, while the joint effect of all the forces in resisting the pressure of the weight is $2\,(y+x)\,b:c$, c being the length of the bars, or $\frac{2by}{c}\cdot\frac{2a}{a+b}$, while the resistance of the two single bars would be $\frac{2by}{c}$, the inclination of the elementary

The comparative security, obtained by the addition of a diagonal brace, is almost without limit. Supposing any number of planks of equal dimensions to lie simply on each other without any adhesion, and to be firmly fixed at one end, their aggregate strength will be very little greater than that of a single plank of one sixth part of the common depth or thickness of each, supported by a brace a little stronger, in the direction of the diagonal of the whole, (fig. 5); and the stiffness of the parallel planks will be as many times less than that of such a frame, as there are planks in one third of the whole series. Thus if we had twelve planks, six inches deep, and one thick, with friction rollers interposed, it is demonstrably true, however surprising, that they would be very little stronger in supporting a weight at the end, than a single tie an inch square in its section, assisted by a diagonal brace of equal relative strength: and also that this apparently slight structure would be nearly four times as stiff as the 12 planks, being depressed only one fourth as much, with a given weight, as the planks with a similar force acting on them.*

forces being here reduced to $\frac{b}{2c}$: and since the magnitude of y at the instant of breaking is given, the force will be augmented by the firmness of the connexion in the ratio of $2a$ to $a+b$, which is always less than that of 2 to 1. The stiffness may be nearly quadrupled by the fastenings, since the depression at the moment of breaking is reduced to little more than one half.

* "If one of the surfaces of a beam were incompressible, and the cohesive force of all its strata collected in the other, its strength would be six times as great as in the natural state." Lect. Nat. Ph. II. 50. Art. 335. Hence a plank of $\frac{1}{6}$ of the actual depth, acting simply as a tie, supported by a brace fixed at the distance of the depth, would be as strong as the original plank: and by increasing the distance of the point of support of the brace in the ratio of the number of planks, the strength of the two arrangements will remain equal, without altering the dimensions of the tie. The length of a plank being e, (Lect. II. 48. Art. 326.) the depth b, the height of the modulus

It is well known, that if the planks were firmly united into one mass, their strength would be rendered 12 times as great by the union, and their stiffness 144 times: but this is not the greatest resistance of which the materials are capable, even without any extension of their base of support; for if the planks were connected in pairs at half the distance of the whole depth, and allowed to move freely round fastenings perfectly secure, their strength, speaking theoretically, would be greater by nearly one half than if they formed a compact mass, while their stiffness would be only about one fourth as great: and an effect nearly similar might be produced if the respective pairs were united by oblique braces, extending over half the depth of the whole structure, although it would be very difficult, in practice, to make the strength of an arrangement of this kind even equal to that of a compact mass, since the fastenings could never be so perfect, as to bring every fibre of each plank into its full action at once, as the theory supposes. If the planks were already united into a compact mass, so as to be incapable of bending except as a whole, it is of importance to inquire whether any advantage would be

of elasticity m, the depression d, and the force applied at the end equal to the weight of a similar plank of the length g, we have $m = \frac{4e^3}{bbd} g$, and $d = \frac{4e^3}{bbm} g$; but, for a simple frame of two equal pieces, the force being g, the longitudinal extending force will be the weight of $\frac{e}{b} g$, and the actual extension $\frac{e^2}{b} \cdot \frac{g}{m}$, and the depression $\frac{2e^3}{bbm} g$, half as great as that of a plank of the same dimensions, when g is given, or supposing the weight on the frame sextuple, so as to be equal to that supported by the plank of six times the depth, three times as great; but by taking 12 planks together, we increase their stiffness only 12 times, while that of the frame is rendered 144 times as great by a similar extension of the base, so that it becomes in this case 4 times as great as that of the 12 planks.

gained by the further addition of oblique braces: and it will appear that if the braces were fixed to the outermost planks of the series only, they would have no manner of effect either on the strength or on the stiffness, whatever might be their direction; but if they were sufficiently fastened throughout their extent to each plank with which they come into contact, they would add both to the strength and to the stiffness, very nearly in the same degree as if they were fixed in the direction of the planks, at a distance from each other equal to their shortest actual distance, so as to constitute as many ribs as there are braces in a transverse line (fig. 6).* Hence, although there is obviously no economy in such an employment of oblique braces, yet it is by no means true that oblique braces are incapable of adding to the strength of a structure composed of pieces arranged at right angles; the assertion might however be very nearly correct in circumstances approaching to those of one of the experiments which have been exhibited for the purpose of illustrating the utility of such braces. On the other hand, the advantage of employing oblique braces must depend in great measure on the degree in which the angular position of the structure would be susceptible of variation without them; since, when properly fastened, they must universally tend to preserve the form unaltered,

* The extension and compression of the whole fabric being supposed equal, the diagonal braces will undergo no change of length, and therefore will not assist in the resistance, if only attached at their extremities. But in reality, although the extension and compression may be very nearly equal in the first instant of the change of form, the extension will always be much greater after a certain time, from the imperfection of the fastenings, which will allow the parts to separate, while their own resistance prevents their compression in a material degree: so that oblique braces, however fixed, must in this respect add considerably to the strength.

although they are somewhat less calculated to add to the ultimate strength of the principal tie or shore, than if their direction had been longitudinal. To take, for example, the case of a ship's arching or hogging: if the strength were overcome without any deficiency of stiffness, the upper decks and wales would be elongated, and the butts of the planks aloft parted, while the keel would be somewhat shortened, and the planks near it crippled, so that a ship 176 feet long and 40 feet deep, arching one foot with a uniform curvature, would have the length of the parts aloft, on the level of the quarter deck, 22 inches greater than that of the keel. If, on the contrary, the strength were not overcome, but the stiffness only failed, the angular situation of the parts being altered, and the joints simply becoming loose without parting, the planks would slide on each other, and their square ends would no longer remain in the same vertical line at the ports, while there would be no material alteration in the comparative length of the decks and keel, nor any permanent parting of the butts of the planks.

Grounds of decision respecting Oblique Riders.

This comparison therefore brings the question, respecting the general utility of oblique riders, into a very narrow compass; and we have only to inquire in what way it is most usual for ships to exhibit symptoms of weakness, in order to decide it. Now it will appear that, in cases of arching in general, some of the butts of the planks are always found to have parted aloft, at the same time that the angular position of some parts of the structure has as uniformly been more or less altered; and very generally a certain degree of sliding is observable in the planks at the sides of some of the ports.

This sliding is seen very distinctly in the planks of the Albion and of the Belliqueux, now at Chatham: at the same time there are also obvious indications of a certain degree of extension and compression: in the Albion, the butts of the planks have parted so far, that in some instances pieces have been let in between them: and in the Belliqueux, there is a space of about five inches between the middle of the deck transom and the carling, which had originally been in contact with it. In the Asia, lately launched in the Medway, the arching amounted to three inches and a quarter, and the comparative length of the upper and lower parts was probably altered about two inches at most: the parting of the butts amounting to $\frac{3}{16}$ of an inch each "for upwards of fifty feet in length in the midships, and for about eight feet from the top of the side," making a total extension of probably less than an inch: so that about half the effect seems to have been produced in one way, and half in the other; but apparently the greater half by the want of stiffness. It is also usually observable, that there has been some degree of permanent compression or crippling below, the butts of the planks opening when the cause of arching has been removed, and the sheathing being more wrinkled than would have happened from the simple bending of the planks. Where it has been observed, that the fore part of all the treenails supported the pressure of the planks in the after part of the ship, and the after part in the fore part of the ship, the observation must probably have been made on the lower parts of the ship, from the effect of a partial compression of this kind.

Authorities.

From this statement it appears, that unless some very strong facts can be produced, to disprove the probability, that the relative angular position of the parts constituting a ship may always be materially altered, without an absolute failure of strength, it cannot be denied that the principle of oblique bracing offers a remedy for the tendency to arch, whatever doubts there may be of the efficacy of any particular mode of applying it. And even if no observations could be produced in confirmation of the frequent occurrence of such a change of the angular situation of the timbers, the supposition that the stiffness could be perfect in this respect, notwithstanding the unequal shrinking of the timbers, and other similar circumstances, while the ultimate strength gave way by the failure of the fastenings, is in itself so highly improbable, that no positive evidence would be required for its complete rejection. We shall find accordingly, that Mr. Bouguer takes for granted the existence of a partial flexure, as sufficiently admissible without direct proof, and recommends the adoption of oblique planking as a remedy; and that other experienced authors have been equally favourable to the employment of some similar arrangements. In speaking of Mr. Gobert's mode of placing the cieling of a ship obliquely, Mr. Bouguer observes, that "this method cannot fail of producing the most desirable effects; for when the planking both within and without was arranged in the direction of the keel, it happened, in case of the ship's arching, that the rectangles formed by the timbers and the planking, merely changed their figure a little, so as to become rhomboids, two of the angles opening a little, while

the other two became more acute: but when the planks of the cieling are laid in an oblique direction, they serve as diagonals to the rectangles, so that a simple change of the relative angular situations of the sides is not sufficient to admit of the arching, without an alteration of the length of the diagonals, which would afford a resistance incomparably greater, especially at the upright parts of the sides, although at the floors it would have but little effect." Traité du navire, 154. Mr. GROIGNARD also, whose memoir, on the improvement of ship-building, has been obligingly communicated to me by an ingenious gentleman, formerly his pupil, although he objects to Mr. GOBERT's method, confesses that he "should have very much approved this mode of disposing the cieling, if it had been possible to employ straight planks, having the same obliquity without interruption, throughout the whole of the ship's length;" but thinks, with BOUGUER, that in carpentry, "every interruption is to be avoided as dangerous;" an objection so vague, as neither to require nor to admit a very distinct reply. Don GEORGE JUAN, too, after a calculation of the absolute strength of the pieces of timber employed in the construction of a ship, very properly remarks, that the effect of arching must be attributed not to their want of strength, but to "their play on each other."

9. *Mr.* SEPPINGS's *Braces.*

It appears therefore to be sufficiently established, that the principle of employing oblique timbers is a good one, provided that it be so applied as to produce no practical inconvenience. We must next inquire whether Mr. SEPPINGS has introduced it in a manner likely to be effectual, and not liable to any

material objections. He places, on the sides of a 74 gun ship, several series of oblique braces, principally between the ports, in the place of the internal planking, making an angle of about 24° with the decks; consisting of planks four inches thick, and about 11 wide, coaked and bolted to the timbers, and abutting against upright pieces similarly fastened. Now it follows, from what has already been stated, that these pieces have about four fifths as much effect in cooperating with the neighbouring parts, which act horizontally, as if they had been placed in the same situation with them, even on the supposition that the relative angular situation of the pieces is unalterably fixed: but for preventing the alteration of this situation, there is no doubt of their being very advantageously arranged, so far as their strength is sufficient; and the existence of a tendency to such an alteration, in a very material degree, appears to be altogether indisputable. Below the gun deck, the oblique timbers are considerably stronger, although they act under circumstances somewhat less favourable.

If, however, the resistance of a part of a structure is very immediately directed against a certain force, without an adequate cooperation from other parts of that structure, and if, being abandoned by those parts, it is exposed to a strain which it is too weak to withstand, it is obvious that it must inevitably be the first to give way, and must leave the rest of the fabric more exposed to be overpowered by such a force, than before its introduction. We must therefore inquire, how far it is possible that Mr. SEPPINGS's braces should be so abandoned. Now supposing a 74 gun ship to arch two feet, and one half of the change to depend on the sliding of the planks over each other, which will be allowed, by those who doubt the utility

of the arrangement, to be fully as much as can ever happen; the greatest fall of the surface will be one foot in 44, and the length of the brace will be diminished $\frac{1}{118}$, or $\frac{7}{10}$ of an inch in the length of six feet, which, with a moderate allowance for the partial yielding of the fastenings, it will be perfectly capable of supporting without being crippled, although indeed it could scarcely support much more. It is obvious, however, that this supposition in many respects far exceeds the utmost that can possibly happen: and it would even require a greater force to produce such an effect on the braces, than any which the ship actually sustains. In order to calculate the magnitude of the greatest strain which these pieces could support, it will be safest to proceed on the supposition, that each square inch of the section of good oak timber is capable of resisting the pressure of four tons on an average: it will then appear that a single series of such braces, as Mr. SEPPINGS employs, extending throughout the length of each side of the ship, would support a weight of 143 tons, in whatever way the force counteracting it might be applied; and estimating the effect of all the braces and riders as equivalent to about four such series, the whole would resist a force of 570 tons; while the greatest force derived from the distribution of the weight, together with the action of such waves as we have considered, amounts to about 450 tons: so that the strength of these braces can scarcely be insufficient to support the pressure, unless the ship should be left dry, resting on the middle of her keel, and the braces should be abandoned by all the other parts, which usually cooperate with them.* The fastenings must indeed

* If a jointed parallelogram, composed of pieces of invariable length, having one of its sides fixed in a vertical position, be supported by a diagonal brace, the compres-

be considerably weaker than this, and the other parts of the ship considerably stronger; but since the fastenings appear to possess sufficient strength to resist any strain which is actually likely to affect them, there seems to be no inconvenience in their inferiority to the other parts. In fact, the Tremendous actually supported, for three days, without any perceptible change of form, a strain fully equal to that which is here calculated, having been purposely left on shores, which extended through 52 feet only of her length. But it must be remembered, that such a force, from its very gradual application, must be much less trying to the ship's strength, than the more abrupt changes which occur at sea, and it must on the whole be inferred, that it would be unsafe to trust to the braces alone, unsupported by the cooperation of the neighbouring parts. It would probably be easy to add some further strength to these braces near the ends of the ship, where the strain on them is the greatest, especially about 30 feet from the head, if it were found that they gave way before the rest of the timbers; and it might also be possible to replace them, if they

sion or extension of the brace will be to the descent of a weight connected with the moveable end of the parallelogram, as the depth of the parallelogram to the length of the brace, whatever the actual distance of the weight may be; so that although the strain on the horizontal pieces increases with this distance, that which affects the brace is independent of it; the relative being to the absolute strength as the depth of the frame is to the length of the brace. We must therefore inquire, what is the greatest absolute force that can be supposed to urge a given portion of the fabric in either direction: thus the excess of weight which has been attributed to the bowsprit and the neighbouring parts being 192 tons at $19\frac{1}{2}$ feet from the head, this force may be occasionally increased by a similar pressure derived from the effect of the waves, which alone would amount to 302 tons at $35\frac{1}{2}$ feet from the head, and which may sometimes cooperate with the former, so as to constitute a force of about 450 tons, about 25 feet from the head.

had once failed, with greater ease than many other parts of the fabric.

It may be questioned how far it is allowable to omit any part of the inner planks between the ports, for which the braces are a substitute, on account of their utility in securing the butts of the planks, which are always made to shift where they are supported by this subsidiary tie: but with the outer planking which remains, and with the partial assistance of the braces, to say nothing of that of the shelf pieces, it can hardly be believed, that the tie is more likely to part between two ports of the same deck, than immediately over one of them.

It has been very ingeniously observed, that arching is not only a part of the evil occasioned by a ship's weakness, but that it has an immediate tendency to afford a partial remedy for the cause which produces it, by making the displacement greater at the extremities of the vessel, and smaller in the middle: but, in fact, this change appears to be too inconsiderable in its extent, to produce any material benefit: the strain at the midships being diminished by each inch of arching only 66 tons, supposed to act at one foot: so that very little relief is obtained from the change, in comparison with the whole strain.

The case of the Kent, which broke in a remarkable degree, notwithstanding the employment of riders of large dimensions, is perfectly reconcileable with the principles which have been laid down: indeed these riders, which made an angle of a few degrees only with a vertical line, could have so little effect either on the strength or on the stiffness of the structure, that there was not the slightest reason to expect any material advantage from their application.

The explanation which has been given of the universal tendency of ships of war, in all common circumstances, to arch throughout their length, is sufficient to justify the different directions in which Mr. SEPPINGS now arranges his braces in the different parts of the ship, since they must necessarily afford a greater strength as shores than as ties, and since the most permanent and the greatest strain will generally be such as to call them into action in this capacity. When, however, a ship is compared to an inverted bridge, it must not be forgotten how necessary it frequently becomes, to consider these braces in a different capacity, and to provide for this contingency, as indeed Mr. SEPPINGS has not neglected to do, by employing such fastenings, as are extremely well adapted to secure their action as ties.

The shelf pieces, which Mr. SEPPINGS employs, and the superior strength of the fastenings of his decks to the breast hooks and transoms, have so obvious a tendency to counteract the causes of arching, that it is unnecessary to insist on their utility: the weight and expense of the shelf pieces are probably the only drawbacks upon the advantages, which they are so manifestly calculated to afford, in resisting both a vertical and a lateral strain; and even in these respects, they appear to be preferable to the wooden knees formerly employed.

The filling up the intervals of the timbers, throughout the hold, with wedges of old stuff, is perhaps the most indisputably beneficial of all the alterations which Mr. SEPPINGS has either introduced, or revived in an improved form. The strength, which is thus obtained, acts immediately in the prevention of arching, and is probably, in this respect, more than an equivalent to that of the internal planking, which has been

omitted; while the cohesive strength of the external planking, considered as a tie, is still probably more than sufficient for resisting the smaller force, which occasionally operates in a contrary direction: although the strength of the ship, for resisting such a force, is certainly much diminished by the change. From the manner in which these wedges are driven by Mr. SEPPINGS, it may easily be understood, that they may tend to produce a convexity below, without raising any part of the keel from the blocks, merely causing it to press more strongly on them at the midships; so that if this difference becomes equal to that of the weight and pressure after launching or floating, there may be no tendency to any further change whatever; and hence it may happen, that without any other superiority of stiffness, or even of workmanship, a ship may appear wholly exempt from arching, as the Tremendous did, and some other ships are said to have done. Without the operation of some such cause, even a hollow cylinder of compact oak, 180 feet long, 50 feet in diameter, and six inches in thickness, if such a mass could be supposed to exist, would exhibit, when immersed to the depth of its axis, a degree of arching just perceptible, from the longitudinal pressure of the water only, amounting to about $\frac{1}{16}$ of an inch;* besides a

* "The stiffness of a cylinder is to that of the circumscribing prism, as three times the bulk of the cylinder is to four times that of the prism." (Lect. Nat. Phil. II. 83. Art. 339. B.): but the radius of curvature of a prismatic beam is $\frac{bbm}{12af}$ (P. 46. Art. 321.) b being the depth, m the weight of the modulus, f the force, and a the distance of its application: and taking m for the weight of the modulus of the cylinder, its radius of curvature will be $\frac{bbm}{16af}$. But since the stiffness is as the 4th power of the diameter, (P. 49. Art. 333.) that of the hollow cylinder in question will

curvature proportionally greater from the other strains, which have been already calculated. Mr. SEPPINGS has also very properly introduced, in the Tremendous, an additional kelson on each side of the step of the mainmast, in order to support its weight, and to prevent the partial sagging of the keel.

10. *Riders.*

With respect to the transverse strain, or the tendency of the sides to sink in comparison with the keel, some strength is probably gained by Mr. SEPPINGS's mode of fixing the filling timbers in the same manner as the frames: and some advantage must be attributed to the cooperation of the wedges, or fillings in, with the timbers, as far as their connexion is capable of bringing them into action. The common cieling is by no means advantageously placed for assisting in a resistance of this kind, since it can only act where the curvature would be increased by the bending of the sides, and even there can only be compressed in a transverse direction (fig. 7). The riders

be reduced in the ratio of 1 to $1 - .98^4 = .0786$. Now when a cylinder is immersed to the depth of its axis, the calculation of the effect of the longitudinal pressure exactly resembles that of the stiffness, the strain being to that which would be the effect of the pressure on the ends of the circumscribing prism as $\frac{3}{4} \times .7854 = .58905$ to 1: but the strain on the prism would be $= 50 \times 25 \times 12.5 \times \frac{50}{3} : 35 = 7440.5$, and for the cylinder, $af = 4383$: and since the height of the modulus of elasticity of oak is 5060000 feet, (p. 509), and its specific gravity nearly equal to that of water, or perhaps a little greater, we have $m = 5060000 \times 50 \times 50 \times .7854 : 35$ tons, and the radius of curvature $.0786 \frac{bbm}{16af} = .0786 . \frac{50^4 \times 5060000 \times .7854 : 35}{16 \times \frac{3}{4} \times .7854 \times 50^4 : (24 \times 35)}$ $= .0786 . \frac{5060000}{12 : 24} = 795432$ feet; and dividing the square of 90 by twice this number, we have .0051, or one sixteenth of an inch, for the versed sine or arching.

commonly placed upon it, on the contrary, are very favourably situated for assisting in this action; but Mr. SEPPINGS's riders are so much more numerous, as to possess, notwithstanding their obliquity, a still greater force. The fastenings of the beams to the sides are also concerned in resisting a strain of this kind, as well as in counteracting the tendency to an extension aloft, which is the more immediate consequence of the unequal pressure of the water against the ship's sides. Mr. SEPPINGS's fastenings, so far as they depend on the shelf pieces, have probably some advantage over the more common ones; but the iron knees, which he employs (fig. 8.) do not appear to be quite so economically arranged as the straps of a simpler form, which other builders have used; they afford indeed a very direct connexion with the timbers, and they save some valuable wood in the chocks which support them: but still there appears to be some waste of strength when they act as ties, from the great obliquity of the shoulders, with respect to the direction of the force; to say nothing of the expense of the workmanship: and if, as Captain CAMPBELL seems to have suspected, there is any slight deficiency in the transverse strength of the Tremendous at the waterways, the circumstance may afford a further reason for doubting of the utility of these fastenings.

11. *Decks.*

The least obvious advantage attributable to the obliquity introduced by Mr. SEPPINGS appears to be in his mode of laying the planks of the decks; parts which seem to be principally required to cooperate with the sides of the ship as ties in a longitudinal direction: for the slight curvature, which is

given to them, can no more render them incapable of such an action, than the bending of a towing rope prevents its pulling along a boat. But in the first place, the lower decks can have little or no action of this kind, from their near approach to the line, at which extension ceases, and compression begins, at least until some of the fastenings give way; and secondly, the upper decks lose but one third of their strength in this capacity, by having their planks disposed at an angle of 45 degrees with the sides, while the obliquity must be capable of affording some additional power of resisting the violent action of the waves, which sometimes produces an immense strain in a transverse or lateral direction, as well as of enabling the ship, in case of necessity, to be more safely "hove down" on her side. There seems also to be some convenience in having the ends of the planks covered by the waterways, with respect to keeping the wings of the ship dry, although it has been suspected that the ends so covered may be rendered somewhat more liable to decay. It may, however, be apprehended, that any force, tending to shorten the deck, will have some little effect in forcing out the sides; for instance, if the whole deck became three inches shorter, the length of the planks remaining the same, they must force out each of the sides about a quarter of an inch, provided that their connexion with the beams allowed such a change, which appears indeed somewhat improbable. There may possibly be a slight difficulty in adjusting the planks to the curvature of the beams; but this difficulty appears to be readily overcome in other cases, as in that of the common cieling. It may hereafter deserve to be inquired, how far an oblique direction of the carlings between the beams, which in their present situation seem to contribute very little

to the strength, might enable them to cooperate in resisting a lateral force, if the arrangement could be made without too much weakening the beams, in procuring proper abutments for these pieces.

12. *Floors.*

It cannot easily be admitted, that Mr. SEPPINGS's construction affords any additional strength to a ship's bottom in case of her grounding. The fillings in between the timbers must indeed be extremely useful in this respect, first by giving firmness in the direction of the length, since even a straight plank is strengthened by having the incompressibility of its outside increased, much more one that is curved, in however slight a degree; and secondly, by cooperating with the timbers, considered as shores, so far as the wedges are fixed in their places by their lateral adhesion or otherwise.

The cieling, which has been omitted, can have very little effect by its own strength in preventing the separation of the timbers at the floor heads; but where there are transverse riders, it must be of essential advantage in enabling these to come into action, for the support of the neighbouring parts exposed to pressure; somewhat more effectually indeed, in many cases, than Mr. SEPPINGS's diagonal riders and their trusses can do, notwithstanding the superiority of their number and aggregate strength; on account of the magnitude of the intervening spaces, which might happen to receive the principal stroke near their centres. This magnitude does not, however, contribute by any means in the same proportion to the weakness of the parts, as it would do if the surface were plane: and it is not improbable, that for supporting the weight of the ship on a very soft ground, Mr. SEPPINGS's arrangement might afford equal strength with the common form, as seems

to have been exemplified by his experiment of leaving the Tremendous for three days on fourteen shores only, without injury: but for encountering the stroke of a rock, or of very hard ground, Mr. SEPPINGS's ship would probably be inferior, since in this case greater stiffness, even with equal strength, would be detrimental rather than beneficial; while, on the other hand, she would undeniably be less liable to suffer from any injury that might happen to her outer planking only; and, from her superiority in this respect, might possibly sustain, without inconvenience, a stroke, which would be ultimately fatal to a ship of a different construction.

13. *Durability.*

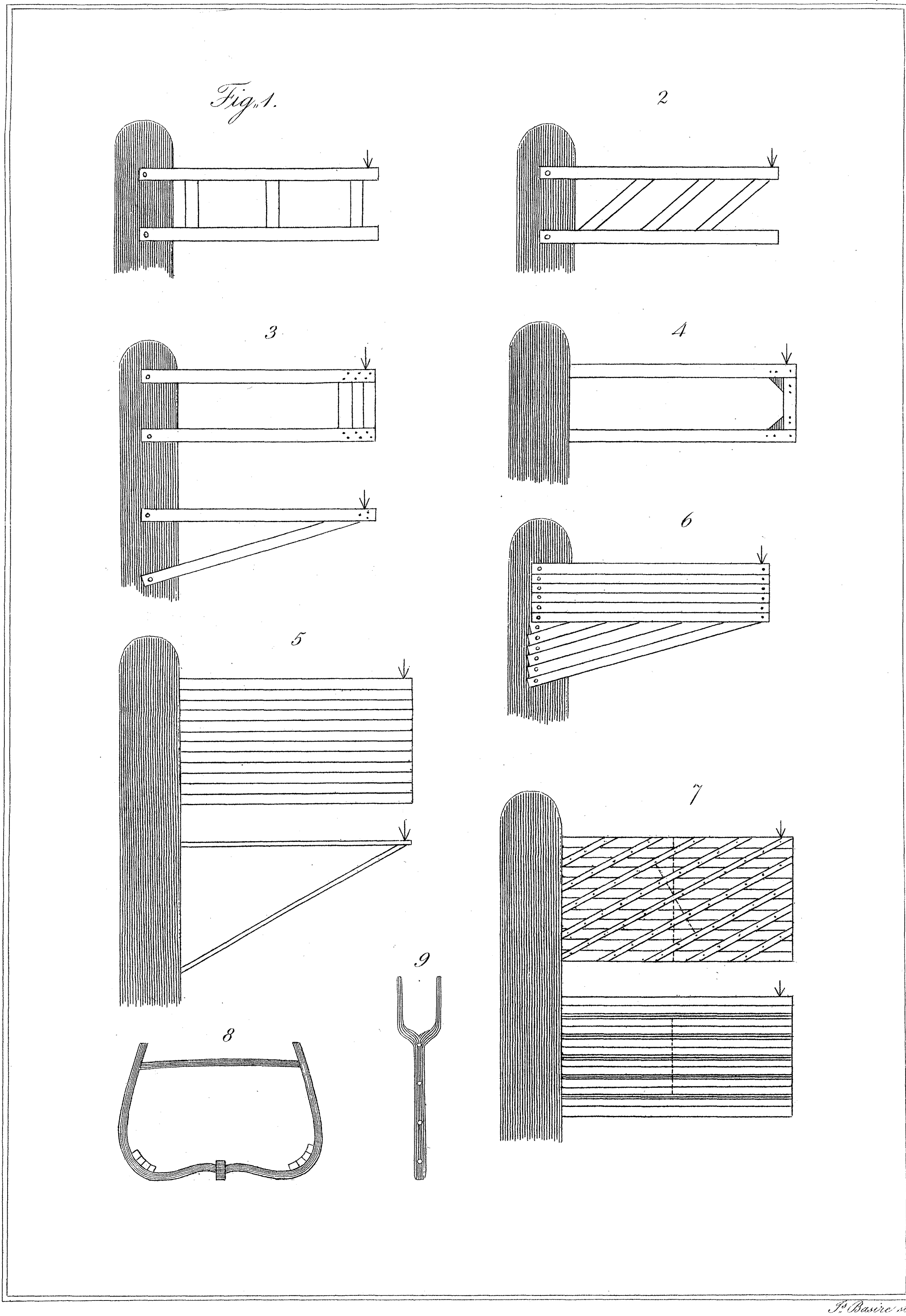
There does not seem to be the slightest ground for the apprehension, that the filling in should render the ship's timbers liable to decay: on the contrary, the timbers of the Sandwich were found perfectly sound in the lower half of their length, opposite to the wedges which had been driven in between them, and completely decayed in the upper half, where they had been exposed, in the usual manner, to the action of the confined moist air and water; and this result is perfectly conformable to analogy with the few facts that have been ascertained, respecting the general causes of decay. The utility of the filling in, for preventing the accumulation of filth, and for keeping the ship free from foul air, with respect to the comfort, and perhaps to the health of the crew, is too obvious to require discussion. How far the economy of timber may in all cases be so great as Mr. SEPPINGS is disposed to believe, can best be ascertained by those who are in the habit of estimating its value: but if the durability of the vessel

only were improved, at an equal expense, the adoption of his alterations would still be highly advisable.

14. *Conclusion.*

It is by no means impossible, that experience may suggest some better substantiated objections to these innovations, than have hitherto occurred: but none of those objections, which have yet been advanced, appear to be sufficiently valid to warrant a discontinuance of the cautious and experimental introduction of Mr. SEPPINGS's arrangements, which has been commenced by orders of the Board of Admiralty. The filling in seems to be wholly unexceptionable: the braces between the ports appear to be decidedly more beneficial than the planks for which they are substituted; and the coakings seem to be very judiciously employed in various parts of the structure: but something more may possibly be hereafter effected for the further improvement of the decks, and for the more complete provision of a substitute for the thick stuff of the cieling, in addition to the diagonal riders, if experience should prove that there is any deficiency in the resistance of these parts. But it must be remembered, in forming conclusions from such experience, that when an arrangement of any kind has nearly attained the maximum of its perfection, it may demonstrably be varied in a considerable degree, without a proportional alteration of its effect; so that the most correct knowledge of scientific principles, and the minutest accuracy in their application, must become indispensably necessary, in order to secure us from the introduction of material errors, derived from the latent operation of accidental causes, foreign to the immediate subjects of investigation.

Welbeck Street, 30 Dec. 1811.



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